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REVIEW ARTICLE - ENGINEERING

The Utility of LiCSBAS to Carry out InSAR Time Series to Analyze Surface Deformation: An Overview

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Abstract

Surface deformation analysis plays a crucial role in understanding geodetic phenomena and their implications for hazard assessment, infrastructure management, and environmental studies. In recent years, the incorporation of synthetic aperture radar (InSAR) and advanced processing techniques have been used to monitor surface deformation. One such technique, LiCSBAS, has shown great promise in analyzing InSAR time series data to accurately detect and quantify surface displacements. It has been successfully employed in various geodetic monitoring scenarios such as landslide monitoring, infrastructure stability assessment, and volcanic deformation analysis. In this study, studies were reviewed in which performance evaluation and comparison of LiCSBAS with other technologies were discussed as well as future developments and challenges in this field. The results of a review of previous studies show the effectiveness of LiCSBAS in detecting and analyzing surface deformation, allowing for a better understanding of geodetic processes. This overview will provide a set of ideas that will assist stakeholders involved in surface deformation analysis and geodetic monitoring and contribute to decision-making to achieve sustainable development.

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1. Introduction

Radar data, mainly synthetic aperture radar (SAR) data, is suitable for surface deformation monitoring [1]. InSAR technology helps the power of satellite radar imaging to detect and monitor subtle changes in the Earth's surface with an accuracy of up to a millimeter [2]. However, reliable and efficient processing tools are required to fully harness the potential of the InSAR time series. LiCSBAS is the best operating system that processes and analyzes InSAR time series data using the SBAS method to identify surface deformation phenomena [3].

The LiCSBAS methodology offers a unique opportunity to overcome the limitations associated with traditional InSAR techniques, such as atmospheric artifacts, decorrelation effects, and temporal decorrelation [3]. In addition, it provides an effective means to detect and measure surface displacements with high precision and accuracy [4]. The analysis of InSAR time series using LiCSBAS has been applied in various domains, including geohazards monitoring, land subsidence assessment, glacier dynamics, and volcanic deformation [5].

Through the utilization of LiCSBAS, researchers and scientists can obtain valuable insights into the temporal evolution of surface deformations and better understand the underlying processes leading to these changes [5]. Accordingly, it becomes possible to assess and mitigate potential risks, devise sustainable land management strategies, and make informed decisions regarding urban planning. The LiCSBAS technique and InSAR time series analysis represent a powerful approach to studying surface deformation. Its ability to accurately capture and monitor surface deformations holds immense potential for scientific research, environmental monitoring, and societal benefit.

This overview aims to evaluate the utility of LiCSBAS in carrying out the InSAR time series technique to analyze surface deformation.

2. InSAR Time Series Technique

Interferometry SAR, in particular, has been widely applied in recent years for approaches implicated in deformation monitoring [6]. A phase interference image known as an interferogram is created using the “Synthetic Aperture Radar Interferometry (InSAR)” technology, which combines two SAR images with almost similar incidence angles (one is typically considered as the master and the other slave). Using InSAR images for topographic mapping with interferometry is undoubtedly an effective method for detecting small, slow changes.

Several satellites are available for collecting InSAR data, such as ALOS POLSAR-2 and TerraSAR, TanDEM-X, HJ-1-C, and RISTAR. However, Sentinel-1 is the most commonly used to obtain data for studying surface deformation in most recent studies.

Nomenclature & Symbols			
GACOS	Generic Atmospheric Correction Online Service	COH	coherence
SAR	Synthetic Aperture Radar	UNW	unwrapped
InSAR	Interferometry Synthetic Aperture Radar	STD	Standard Deviation
LiCSAR	Looking into Continents from Space with Synthetic Aperture Radar		

InSAR has been widely used to monitor land subsidence, which can result from factors such as groundwater extraction, hydrocarbon extraction, and natural compaction processes [4]. Moreover, InSAR time series analysis plays a crucial role in understanding tectonic processes and seismic activity by monitoring surface deformation associated with tectonic plate movements, fault slips, and seismic events [7, 8]. InSAR time series analysis provides valuable information on the distribution of deformation, fault segmentation, and long-term deformation rates, aiding in seismic hazard assessment and earthquake forecasting [9].

3. LiCSBAS Package

3.1. LiCSBAS definition

LiCSBAS is an open-source InSAR time series analysis tool that interfaces with LiCSAR, created by Yu Morishita [10]. Users do not have to create interferograms from SLC data because LiCSAR products are used. Instead, LiCSBAS makes it simple for users to get InSAR time series and velocity estimations in locations where enough LiCSAR products are available.

LiCSBAS is a free software system that runs entirely on Python 3 and the Bourne Again Shell (bash) the source codes are accessible on GitHub [10]. LiCSBAS provides InSAR data throughout LiCSAR data-processing platform. It is a compilation of Sentinel-1 interferogram data that is available through the COMET-LiCS webpage [3]. LiCSBAS analysis InSAR time-series and is used to evaluate LiCSAR results [3].

3.2. LiCSBAS methodology

The workflow of the InSAR time series processor can be divided into two main sections: Step 0 - Stack of unwrapped data preparation, and Step 1 - Time series analysis as shown in Fig. 1.

3.2.1. Step 0 - Stack of unwrapped data (LiCSAR Products)

- Step 0-1: Download LiCSAR products relevant to the selected study area.
- Step 0-2: Convert the data into the required format.
- Step 0-3: Process interferograms from other satellites (besides Sentinel-1) if they meet the compatibility criteria.
- Step 0-4: Masking of unwrapped data to increase accuracy and efficiency.
- Step 0-5: Clip unwrapped data to further improve processing efficiency.
- Step 0-6: Tropospheric noise correction using external data from the Generic Atmospheric Correction Online Service for InSAR (GACOS) [11].

3.2.2. Step 1 - Time series analysis

- Step 1-1: Assess coherence and coverage of unwrapped data.
- Step 1-2: Perform a loop closure check to identify and eliminate wrongly unwrapped data that could affect the results.
- Step 1-3: Invert the refined stack of unwrapped data to obtain displacement time series and velocity.
- Step 1-4: Estimate velocity standard deviation (STD).
- Step 1-5: Mask noisy pixels using various noise indices.
- Step 1-6: Apply a spatiotemporal filter to reduce remaining noise and generate filtered time series and velocity.

3.2.3. Output and export

- The processor can export the output (velocity and time series) in GeoTIFF, KMZ, or text format.
- The results can be visualized and interactively explored using a time series viewer.

The entire workflow, including both Step 0 and Step 1, can be executed using a batch script with specified parameters or through the command line. LiCSBAS provides a comprehensive and efficient solution for InSAR time series analysis, supporting both Sentinel-1 data and other compatible interferograms from different satellites. The processor's implementation in Python and Bash makes it accessible and versatile for various research applications.

4. Utility of LiCSBAS in Analyzing Surface Deformation

Several studies have demonstrated the utility and effectiveness of LiCSBAS in analyzing surface deformation across various geospatial phenomena as explained in the following:

4.1. Land subsidence

Morishita (2021) [12] used LiCSBAS to analyze InSAR data and quantify land subsidence rates between 2014 and 2020, in 73 significant Japanese urban regions. Ghorbani et al. (2022) [4] have also used LiCSBAS to analyze InSAR data and quantify land subsidence in other regions, such as the Ardabil Plain in Iran.

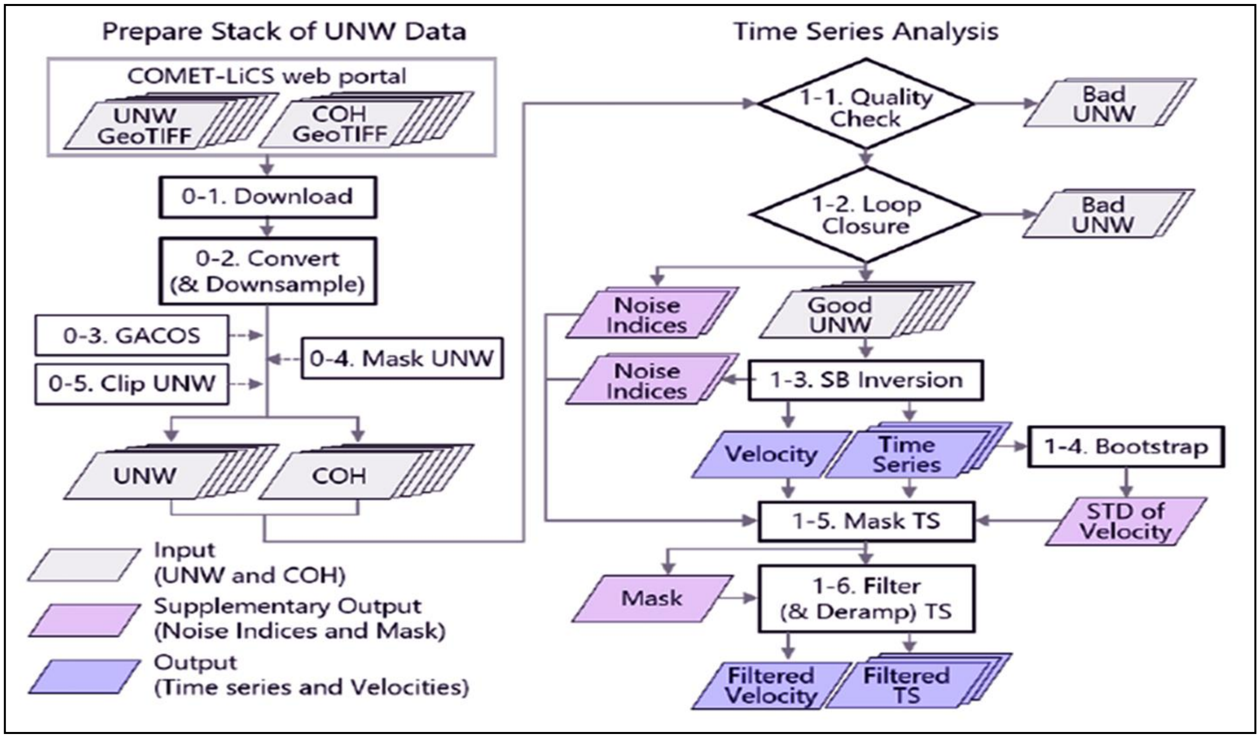

Fig. 1. The processing of unwrapped (UNW) interferometric phases and coherence (COH) data [3]

4.2. Volcanic deformation

LiCSBAS provides valuable information for volcanic hazard assessment and eruption forecasting such as uplift and subsidence patterns that correlated with the volcano's eruptive phases, thus LiCSBAS has been employed in studying volcanic activity and its associated surface deformation in the case of Mount Raung, located in East Java, Indonesia.

Kriswati et al. (2021) [16] used LiCSBAS to analyze InSAR data and track the volcano's deformation over several years. The results showed that the rim and crater of the volcano have stable inflation and deflation although there are short-term fluctuations in inflation and deflation.

4.3. Plate tectonic movements

LiCSBAS is also used to analyze InSAR in investigating tectonic plate movements and associated deformation in several studies. Lazeckỳ et al. (2020) [5], used LiCSBAS to analyze InSAR data and compute the strain accumulation and release along the North Anatolian Fault in Turkey. The results helped identify areas of increased seismic hazard and provided insights into the fault's behavior and slip rates.

LiCSBAS has also been applied to study other tectonic regions, such as Southern Sumatra in Indonesia study by Ghiffari et al. (2022) [13] and Yusiyanti et al. (2023) [14].

4.4. Landslide monitoring

LiCSBAS is utilized to analyze InSAR in monitoring landslides and slope stability which facilitates better understanding, assessment, and management of various environmental and geotechnical processes. Rosyidy et al. (2021) [15] used LiCSBAS to analyze InSAR time series data, to detect and calculate surface displacements that are associated with landslide activity in Sukabumi Area, Indonesia. The results were suitable to use to support regional development planning in reducing losses and casualties facilitating landslide hazard assessment, and early warning systems.

5. Difference Aspects Between Traditional InSAR and LiCSBAS

The important difference aspects between traditional InSAR and LiCSBAS have been summarized and listed in Table 1.

Table 1. Comparison between the Traditional InSAR method and LiCSBAS

Aspect	Traditional InSAR	LiCSBAS
Principle and Methodology	A measure phase difference between radar signals	Selects a subset of interferograms with small baselines
Temporal Coverage	Limited by the number of interferograms	Expanded coverage with analysis of longer time series
Spatial Coverage	Determined by satellite imagery and radar swath	Enhanced coverage by selecting small baseline interferograms
Processing Complexity and Data Requirements	Complex processing and extensive data correction (manually) by using Snap and Snaphu.	Reduced complexity and data requirements (automated)
Disk space and time processing	Needs a large disk space and it’s time-consuming	Needs a small disk space and the process can be done in an extremely short period

Accuracy and Precision	Accurate but affected by atmospheric artifacts and temporal decorrelation	Improved accuracy and precision, with the Generic Atmospheric Correction Online Service for InSAR (GACOS).
Data Availability and Accessibility	Depends on satellite missions and data policies	Utilizes publicly available InSAR datasets and existing data sources (sentinel-1 C- band). It can be used to process data from other satellites
User	Needs extensive knowledge of InSAR techniques to fully exploit the data	Doesn't need extensive knowledge

6. Limitations of the Use of the LiCSBAS Method

LiCSBAS has been developed in various aspects in recent years and some of these aspects are given below (Morishita et al. (2020) [3]).

- It is difficult to detect the detailed deformation time series in the highly vegetated areas using existing C-band SAR data because Interferograms within 24 days and longer lose coherence.
- InSAR time series data's growing volume and complexity require advancements in big data analytics and high-performance computing to handle the processing and analysis efficiently. This would enhance the usability and practicality of LiCSBAS for widespread application in real-time monitoring and decision-making.
- LiCSBAS performance can be affected by data gaps, irregular acquisitions, and spatial inhomogeneity in the InSAR datasets.

7. Results and Discussion

An analysis was conducted to assess the efficacy of LiCSBAS in utilizing InSAR time series for the study of surface deformation in several studies. It has been observed that LiCSBAS is capable of analyzing LiCSAR products, which employ Sentinel-1 interferometric processing to monitor active deforming regions and provide a response to events such as earthquakes or volcanic eruptions [4]. Also, it has been noted that LiCSBAS can accurately capture and quantify large-scale deformations, with an accuracy of less than 1 cm at each epoch and approximately 2 mm/year in velocity. This feature is particularly useful in monitoring slow-moving landslides, subsidence in urban areas, and tectonic plate movements. The ability of LiCSBAS to analyze time series data makes it possible to identify temporal changes and detect deformation patterns and trends over long periods [3].

LiCSBAS has the added advantage of being robust to handle even in regions subject to large atmospheric forcing or rapid land cover changes with GACO. LiCSBAS' computational efficiency allows large-scale data sets to be easily processed, reducing processing time and resource requirements.

It is noted that LiCSBAS has some limitations which highly depend on the availability of a stable network of SAR images and adequate temporal coverage.

8. Conclusions

According to the reviewed studies evaluating the utility of LiCSBAS in implementing an InSAR time series for surface deformation analysis, LiCSBAS is a powerful tool for surface deformation analysis using InSAR time series, providing high accuracy, robustness against environmental perturbations, and computational efficiency. While it has limitations, its advantages outweigh these challenges, making it a valuable technique for understanding and quantifying surface deformation dynamics.

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